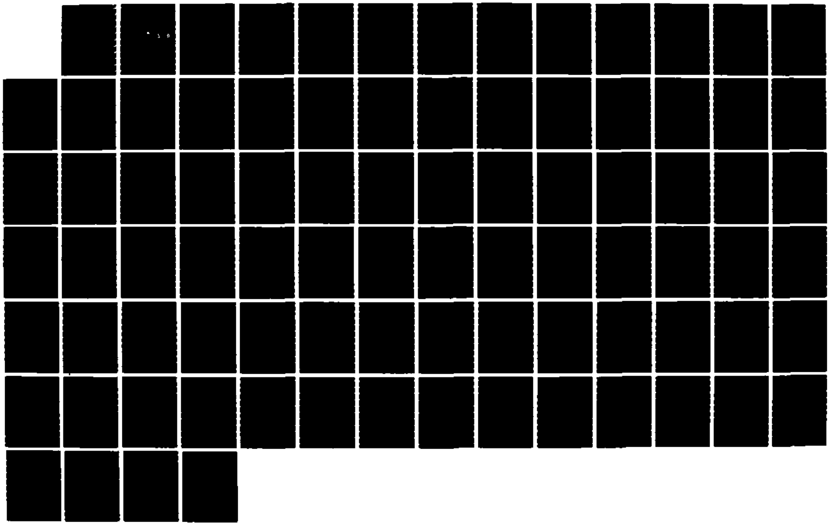
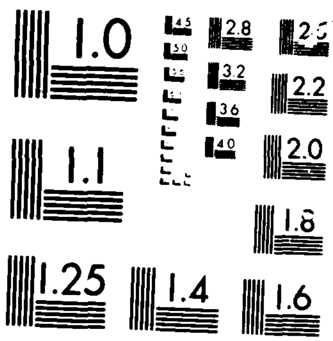
AD-A169 130 CAN EXPERT SYSTEM HELP TRAIN TACTICAL ACTION OFFICERS: 1/1
SOME EXPERIENCES FROM AN EARLY PROTOTYPE(U) NAVAL
POSTGRADUATE SCHOOL MONTEREY CA S ZIVOVIC MAR 86

UNCLASSIFIED F/G 5/9 NL





MICROCOP ... CHART

2

AD-A169 130

NAVAL POSTGRADUATE SCHOOL

Monterey, California

DTIC
ELECTE
JUL 02 1986
S D
D

THESIS

CAN EXPERT SYSTEM HELP TRAIN TACTICAL ACTION OFFICERS:
SOME EXPERIENCES FROM AN EARLY PROTOTYPE

by

Sreten Zivovic
March 1986

Thesis Advisor: Tung Bui
Co-advisor: Taracad Sivasankaran

86 7 1 087

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION	1b. RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S)	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION Naval Postgraduate School 6b OFFICE SYMBOL (If applicable) Code 54	7a NAME OF MONITORING ORGANIZATION Naval Postgraduate School
6c ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000	7b ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000
8a NAME OF FUNDING/SPONSORING ORGANIZATION 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO / PROJECT NO / TASK NO / WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)
CAN EXPERT SYSTEM HELP TRAIN TACTICAL ACTION OFFICERS: SOME EXPERIENCES FROM AN EARLY PROTOTYPE

12 PERSONAL AUTHOR(S)
Zivovic, Sreten

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Master's thesis	FROM ____ TO ____	1986 March	85

16 SUPPLEMENTARY NOTATION

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Tactical Action Officer, TAO, Tactical Decisions, Tactical Decision Making, Training Prototype for TAO, Expert System for TAO, Knowledge-based TAO

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

The variety and complexity of modern weapon systems demands great skill on the part of the Tactical Action Officers (TAOs) in correctly analyzing the threat, and taking appropriate countermeasures, during a naval engagement. Not only do the TAOs need to have the rules of engagement at their fingertips but they also need to apply them in an optimum manner, quite often, within extremely short reaction times. It takes considerable time, effort and experience to perfect the art of TAO decision making.

This thesis develops a generic model of the TAO decision making process. A prototype TAO expert system is implemented based on the model. The prototype is designed to run on a microcomputer. The system is a pioneering effort in applying artificial intelligence towards supporting TAOs in the accomplishment of their duties. Furthermore, such a system may also be used for training student TAOs.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL Tung Bui	22b TELEPHONE (Include Area Code) (408) 646-2630 22c OFFICE SYMBOL Code 54Bd

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

Block 18. (cont'd)

Trainer.

Approved for public release; distribution is unlimited.

Can Expert System Help Train Tactical Action Officers: Some Experiences From an Early Prototype

by

Sreten Zivovic
Lieutenant Commander, United States Naval Reserve
B.A., University of Illinois, 1973

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN INFORMATION SYSTEMS

from the

NAVAL POSTGRADUATE SCHOOL
March, 1986

Author: Sreten Zivovic
Sreten Zivovic

Approved by: Tung Bui
Tung Bui, Thesis Advisor

Taracad Sivasankaran, Thesis Co-Advisor

Willis R. Greer Jr., Chairman,
Department of Administrative Sciences

Kneale T. Marshall
Kneale T. Marshall,
Dean of Information and Policy Sciences

Distribution/
Availability Codes
Dist | Avail and/or Special
A-1

ABSTRACT

The variety and complexity of modern weapon systems demands great skill on the part of the Tactical Action Officers (TAOs) in correctly analyzing the threat, and taking appropriate countermeasures, during a naval engagement. Not only do the TAOs need to have the rules of engagement at their fingertips but they also need to apply them in an optimum manner, quite often, within extremely short reaction times. It takes considerable time, effort and experience to perfect the art of TAO decision making.

This thesis develops a generic model of the TAO decision making process. A prototype TAO expert system is implemented based on the model. The prototype is designed to run on a microcomputer. The system is a pioneering effort in applying artificial intelligence towards supporting TAOs in the accomplishment of their duties. Furthermore, such a system may also be used for training student TAOs.

TABLE OF CONTENTS

LIST OF FIGURES

I. INTRODUCTION

A. THE PROBLEM

A Tactical Action Officer (TAO) in a Navy ship is susceptible to making less than optimum tactical decisions under any given set of conditions. The TAO's goal is to always make the best analyses of the threat and to take the most appropriate defensive or offensive action(s). The quality of the TAO's decisions is greatly dependent on his experience and training.

One of the causes of the problem appears to be the low level of experience and training of the TAOs in the fleet. Some of the reasons for this situation could be the personnel assignment/rotation policy, and lack of or an insufficient number of realistic exercises and or deployments.

A possible solution to this problem is to provide some means of a reasonably consistent method of tactical decision making. In addition, an acceptable (relatively low cost and easy to implement) means of transferring "know-how" from those who have the knowledge to those who are willing to learn is required.

B. BACKGROUND

The sophistication of modern weapon systems allows very little response time for the TAO to make tactical decisions on board a Navy ship during a Naval engagement. The variety

and complexity of these weapon systems further contribute to the difficult task faced by the TAO of correctly analyzing the threat and taking appropriate countermeasures. Furthermore, environmental factors such as TAO fatigue and the level of activity (and noise), impact on the quality of TAO decisions. And of course, the level of expertise and experience varies from one TAO to another.

Chapter II deals more specifically with the TAO and the TAO environment. An example demonstrating the complexity of the TAO decision making is also included therein.

It takes considerable classroom preparation and a lot of on the job training to develop a TAO qualified Officer. A TAO is normally an Officer with at least four years (often more) of experience on the job and several periods of formal school and the simulator training. The "best" TAO training, in peace time, can be obtained only during the actual fleet deployments and participation in fleet exercises. Both of these options are controlled by higher authority (designed to support the needs of the Nation) and are not readily available for the TAO training. It takes a lot of time and resources, as well as "good" timing on the part of an individual, to train fleet TAOs.

The problem is further compounded due to personnel turnover resulting from typical Naval Officer career path. After gaining a few years of experience, qualified TAO's move

to other jobs and other, younger and less experienced Officers, start their own TAO learning process.

C. THESIS OBJECTIVES

The purpose of this thesis is to develop a "knowledge based", expert system prototype of the TAO decision making process. The prototype is intended to demonstrate the feasibility of developing an expert system in the area of military tactical decision making. Specifically, the prototype should demonstrate suitability and potential performance of an expert system to make tactical decisions and recommendations to the TAO during a limited scale naval engagement in a hot war environment. The prototype can be used in a training environment to train personnel and to serve as a test bed for future developments. It will utilize any information about its environment and the existing knowledge base to derive tactical decisions. Such a prototype could be useful in the development of a full scale computer based TAO expert system. We will investigate the factors involved in the tactical battle management decisions, study the environment and implement a TAO expert system prototype.

D. WHY AN EXPERT SYSTEM?

1. Complexity of the Domain

There are several reasons for choosing a knowledge based approach to solve the TAO problem. In today's military

environment, the range of possible weapons is so large that it is very unlikely a TAO would be able to consider all the possible characteristics of the weapons, remember all of the "Rules of Engagement," and make the correct determination of the platform in question. The TAO, then has to consider all of its potential weapons and decide on the "optimum" course of action he must take in the time available.

It can be observed that TAOs get tired and therefore may fail to consider all the known factors and all of the possible solutions to a given situation. They may make a decision based on the information they know (or remember) best, or are the most comfortable with and what they hope will work, and then move on to the next problem(s). Invariably, upon review of such actions and decisions, the decision maker almost always chooses a different method of solving the same problem.

2. <u>Speed and Accuracy of Data and Information Processing</u>

Modern Warfare does not allow sufficient reaction time to TAO for evaluating all alternatives before an optimum one is chosen. Furthermore, the data collected by the sensors must be processed accurately. Therefore, one of the primary reasons for choosing a knowledge based approach to the TAO problem is the very high speed with which the computer processes data (in this case the inputs from various ship sensors). The availability of computers and electronic data storage and retrieval procedures can help with the

verification of data obtained by the various sensors on board a ship. Such data can be compared at high speeds with the stored library of "known" characteristics of various platforms and weapon systems. This would eliminate or reduce the potential for the operator error in identifying and classifying the raw data which he has received on his equipment. However, this capability by itself does not help the TAO to analyze all the other various concerns which go into making his decision based on the particular sensor input. An EXPERT SYSTEM is needed to help him do that.

3. Behavior Under Pressure

The second reason is the ability of the knowledge based system to search vast knowledge bases, conduct comparative analysis and derive accurate decisions. The main advantage of the "knowledge based" expert system programs is that they don't have to operate "under pressure" as human operators often have to do. In particular, they will not take fatal "shortcuts" while under pressure to meet deadlines and will not forget or mix up the knowledge which they may have.

4. Transfer of "Know-How"

The third reason is the "knowledge based" system's ability to transfer "know-how." Construction of the TAO expert system involves collecting knowledge in the TAO domain (Naval engagement) and storing that knowledge so that it can be processed by the computer and presented to the user

(TAO or TAO trainee) to enhance his/her decision making process. In this manner, the experience and the "corporate knowledge" would not be lost every time the experienced TAOs are transferred to another command. A computer system is ideally suited for just such an environment. If the knowledge base is properly constructed and the production rules truly reflect an expert in the domain, than it is expected the system will provide correct recommendations given the proper environmental inputs. A TAO expert system can assist the TAO in the accomplishment of his mission (defending the ship and/or offensive action against an enemy).

5. Explanation and Reasoning

Finally, the "knowledge based" system has the ability to provide consistent and precise explanation of reasoning used that led to the system's decision.

II. DESCRIPTION OF DOMAIN KNOWLEDGE

A. THE TAO CONCEPT

A TAO is that Officer on watch in a Navy ship who is qualified, and designated in writing by the Commanding Officer of the ship, to manage ships personnel and equipment, including all ships weapon systems and the propulsion plant, in time of war or in peace, consistent with the command policy and the policy of higher authority. He is specifically authorized to take direct action, using ship's weapons, Combat Air Patrol (CAP) under ship's control and/or Electronic Countermeasures (ECM) to fight the ship when the tactical situation demands. The TAO has the responsibility and the authority to defend the ship and is responsible directly to the ship's Commanding Officer for his actions and decisions. He is experienced in tactical decision making in a Naval environment.

1. Qualifications

The TAO's qualifications should include (this is an example only) the following [Ref. 1]

* A background of knowledge and experience in Anti-Air-Warfare (AAW), Anti-Submarine-Warfare (ASW), Electronic-Warfare (EW), Amphibious-Warfare (AMW), and Anti-Surface-Warfare (ASuW), including a detailed knowledge of his own ship's weapons and propulsion capabilities and limitations.

* A good knowledge of the characteristics, capabilities, and limitations of fighter, attack, ASW, EW, and Airborne Early Warning (AEW) aircraft, their associated weapons systems and their means of employment.

* Familiarity with AAW, ASW, EW, sensors including radar, sonar, and Electronic Surveillance Measures (ESM) equipment employed by his own ship and other units operating in the area.

* A familiarity with available intelligence on pertinent, potential enemy tactics and doctrines and substantial knowledge about the capabilities and limitations of enemy hardware resources, including platforms as well as Anti-Ship-Cruise-Missiles (ASCM's).

* Knowledge of the procedures utilized for air intercept control (AIC) and for CAP/missile coordination.

2. <u>Organization</u>

There are several different implementations of the TAO concept in the Navy today. A specific TAO organization depends on the type of ship, the ship's weapons suite and the ship's mission. A sample TAO organization is provided in Fig. 1 below for illustrative purposes only. It shows only the basic command and control relationships.

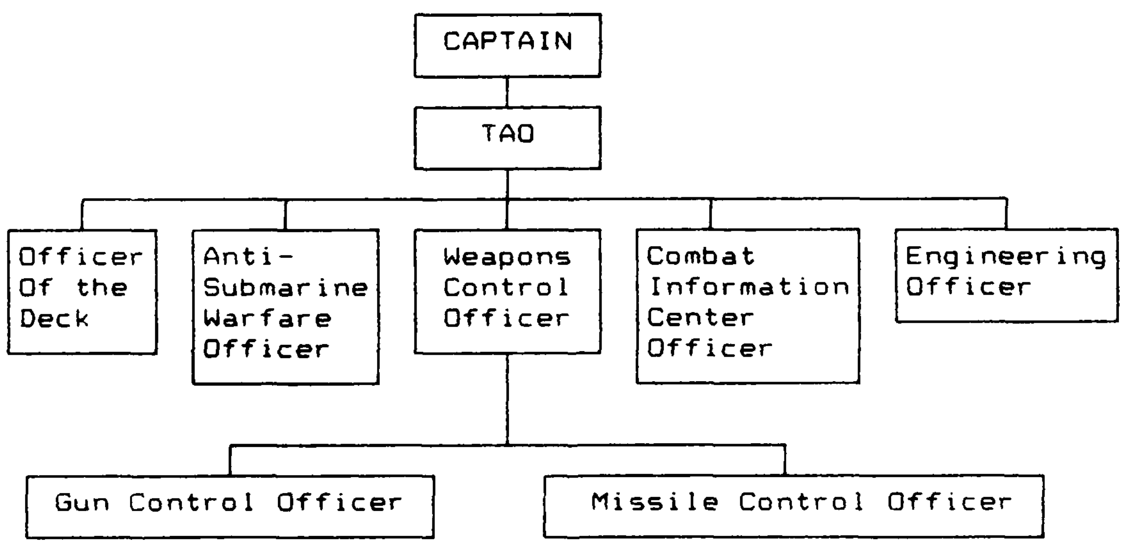


Figure 1. TAO Command and Control Diagram (an example)

B. ENVIRONMENT AND THE TAO DECISION MAKING PROCESS

1. Environmental Impact

Tactical decisions on board Navy ships are made by the ship's captain and by the TAO who acts as the captain's alter ego. Although many ships have various levels of automation in the area of information processing and decision making, it is the TAOs who make the final decisions (consistent with the command policy). These decisions are based on the TAO's experience, his ability to analyze the situation and to remember and apply the rules and doctrines under which he is operating at the time. Of course, he must also remember or have ready access to various amounts of reference data regarding the operating characteristics of friendly and enemy platforms and weapons systems.

For example, the TAO must know the status and capabilities of his own ship including all weapons systems, the status of the engineering plant and the "Rules of Engagement" under which he is operating, as well as the policy of his commanding officer. In addition, the TAO must be very knowledgeable of the characteristics and capabilities of "friendly" platforms and weapon systems. He must also possess a great deal of knowledge about the "enemy" platforms and weapon system capabilities and weaknesses. Other, less clearly defined factors which must be considered by the TAO are the prevailing weather conditions in the area of operations, the visibility issues, the political situation in

the world and in the immediate operating area and the presence or absence of "neutral" or commercial shipping or aircraft. And of course, the physical proximity of friendly or hostile land masses or operating/logistic bases must also be considered.

2. A Situation at Sea (a scenario)

To illustrate some of the above concerns we can construct the following situation: During an exercise at sea, the visibility is poor, the weather is bad with high winds and very heavy seas. The intelligence information indicates a possible enemy submarine in the area. This particular submarine is believed to be the type which has to surface in order to fire its anti-ship missile. The ship has been on patrol, trying to detect this submarine for several days with no success. The ship's sonar detection capabilities are reduced due to heavy seas. There is some shipping in the general area in which the ship is operating and this is contributing to the already difficult task of detecting any submarine noise on the sonar. People are tired and anxious for the weather to break. Everyone is hoping for a sonar contact on the submarine. A sonar contact would immediately invoke the combat team procedures, where people are performing tasks for which they have been trained, and the boredom and any discomfort caused by the heavy seas would immediately be replaced with a rush of adrenaline and "bee-hive" type activity. The section on watch consists of the

experienced operators and technicians with an excellent record of sonar contact detections and classifications.

The TAO is informed by his Electronic Warfare (EW) specialists that they have an Electronic Surveillance Measure (ESM) emission which corresponds to the type of missile acquisition radar known to be on the type of submarine the ship has been trying to detect for the past few days. There are no surface or air contacts on any of the radars and no other ESM emission. The EW on watch is one of the best and most experienced technicians on board the ship, and has provided very reliable and accurate information in the past. It is also known that it would be near impossible for that submarine to be surfaced in this kind of sea state and to have its missile doors open. The TAO must make some kind of decision(s) and he must make such decision(s) fast. What does he do?

The bottom line is that we rely heavily on the TAO's ability to identify and synthesize large amounts of diverse, and often contradicting information, to form judgments, evaluate alternatives, and make decisions. This is what makes TAO an expert in his field.

C. THE TAO INFORMATION OVERLOAD AND TIME PRESSURE

During a simulated or an actual engagement with an enemy, the amount of information in Combat Information Center (CIC), which is where the TAO operates from, is usually overwhelming. In addition to several radio circuits which

are providing various information to personnel in CIC, there are many other reports being generated by the various personnel on watch. All these reports must be heard, acknowledged, analyzed and some sort of disposition made on them by the TAO. At the same time, the TAO must not forget the status of his weapons, the position and movement of his ship and the ships around him, and he must not forget the enemy's actions or his position. He must overcome the information overload and keep clear head in order to make the best possible judgments regarding own ship actions as well as the possible actions of the enemy.

In an environment such as this, and with the tremendous variety of weapons systems and platforms in the arsenals of various nations, it is easy to imagine that rules can be forgotten, weapon system characteristics can be incorrectly attributed to a specific weapon and the decision to counter the threat can be based on incorrect assumptions about the threat or the situation. Often, decisions are made without the complete analysis of the known or available information in order to "move on" to the next (pressing) item. The end result is less than optimum decisions being made by TAOs which can have potentially catastrophic results to the ship and to the overall policy of the higher authority.

III. AI AND EXPERT SYSTEMS

This thesis applies techniques developed in Artificial Intelligence (AI), particularly Expert Systems(ES), to the TAO decision making process. Hence it might be relevant to summarize the technology of Artificial Intelligence and Expert Systems before we proceed further. Sections A and B briefly review some of the most important issues in the knowledge engineering field. Based on the discussion material in this chapter, Chapter IV will analyze the potential applicability of AI into the Tactical Decision Making Process. Readers who are already familiar with the area of Artificial Intelligence and Expert Systems may skip this chapter without loss of continuity.

A. BACKGROUND

Artificial Intelligence is the "hot" topic in many circles within the computer industry today. This is due in a large part to the advances which have been made in recent years, both in software and in hardware. Artificial Intelligence is certainly not a new field, and it has its origins in the early works of pioneers like H. A. Simon, A. Newell, A. M. Turing, and others.

Within the broad spectrum of Artificial Intelligence is the field of "Knowledge Engineering." This area was developed as a solution to the combinatorial complexity

associated with real-world problems and the realization that the search techniques or computational logic alone (prevalent methods of finding solution(s) to problems in the AI community at the time) proved to be inadequate to solve real complex problems. A problem in this context is defined as the situation in which a decision maker finds himself when he is faced with the task of choosing one of a set of alternatives placed before him by the problem environment.

Feigenbaum and Feldman [Ref. 2:pp. 5-6] state:

> What is troublesome about alternatives is not so much their number as their consequences. Alternatives usually have elaborate consequences, which need to be evaluated before one alternative is chosen. . . . highly selective search, the drastic pruning of the tree of possibilities [is needed] . . . it must search problem mazes in a highly selective way, exploring paths relatively fertile with solutions and ignoring paths relatively sterile.

A sequential search and examination of each alternative, using numerical classical search techniques, is simply not adequate, often leading to unacceptable search times, due to the combinatorial explosion of alternatives. In order to mitigate the complexity of real-word problems and to limit the alternatives to be searched/examined in a large problem space, "knowledge based" systems rely on "heuristics."

Feigenbaum and Feldman [Ref 2:p.6] state:

> A heuristic (heuristic rule, heuristic method) is a rule of thumb, strategy, trick, simplification, or any other kind of device which drastically limits search for solutions in large problem spaces. Heuristics do not guarantee optimal solutions; in fact, they do not guarantee any solution at all; all that can be said for a useful heuristic is that it offers solutions which are good enough most of the time . . . . The payoff in using heuristics is greatly reduced search and, therefore,

practicality. Often, but not always, a price is paid: by drastic search limitations, sometimes the best solution (indeed, any or all solutions) may be overlooked.

Heuristics are heavily employed in various Expert Systems and in the "knowledge based" approach to problem solving.

B. WHAT IS AN EXPERT SYSTEM?

Expert Systems are a special area of Artificial Intelligence. They use knowledge and inference procedures to solve problems. Expert Systems differ from more conventional computer programs in that they have a clear separation of data and the rule inference machine.

Feigenbaum [Ref. 3:p. 1], one of the pioneers in expert systems, states:

> An "expert system" is an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution. The knowledge necessary to perform at such a level, plus the inference procedures used, can be thought of as a model of the expertise of the best practitioners of the field.
>
> The knowledge of an expert system consists of facts and heuristics. The "facts" constitute a body of information that is widely shared, publicly available, and generally agreed upon by experts in a field. The "heuristics" are mostly private, little-discussed rules of good judgment (rules of plausible reasoning, rules of good guessing that characterize expert level decision making in the field. The performance level of an expert system is primarily a function of the size and quality of the knowledge base that it possesses.

Hayes-Roth [Ref. 4] provides an even more specific definition of Expert Systems:

> An expert system is a knowledge-intensive program that solves problems normally requiring human expertise. It

performs many of the secondary functions that an expert does, such as asking relevant questions and explaining its reasoning . . . . [Expert Systems do the following]

* They solve very difficult problems as well as or better than human experts.
* They reason heuristically, using what experts consider effective rules of thumb.
* They interact with humans in appropriate ways, including the use of natural language.
* They manipulate and reason about symbolic descriptions.
* They function with erroneous data and uncertain judgmental rules.
* They contemplate multiple competing hypotheses
* simultaneously.
* They explain why they're asking a question.
* They justify their conclusions.

Expert systems are also known as "knowledge based" systems. They contain a vast amount of domain specific knowledge and always provide some answer even if only partial information is available.

The basic structure of an Expert System consists of:

1. a knowledge base
2. an inference procedure
3. a working memory.

The knowledge base contains domain facts and heuristics associated with the problem. It is normally developed by a knowledge engineer and a human domain expert. An inference procedure utilizes the knowledge base in the solution of the problem. A working memory is used for keeping track of the problem status, the input data for the particular problem, and the relevant history of what has been done thus far.

There are many written works on Expert Systems and knowledge bases and it is not the purpose of this thesis to review all of them. However, a generally acceptable view, in it's simplest form, is that an expert system is a repository of knowledge about a specific domain, and procedures for applying that knowledge.

IV. THE TAO EXPERT SYSTEM PROTOTYPE DEVELOPMENT PROCESS

A. INTRODUCTION

We have already addressed the need for a TAO Expert System Prototype in Chapter I (Sections C and D). Five distinct phases are involved in building the unclassified prototype. Figure 2 [derived from Ref. 5] shows these phases. The test and validation phase will be performed during the acceptance of the prototype at the end of the project and in subsequent usage during training and demonstrations.

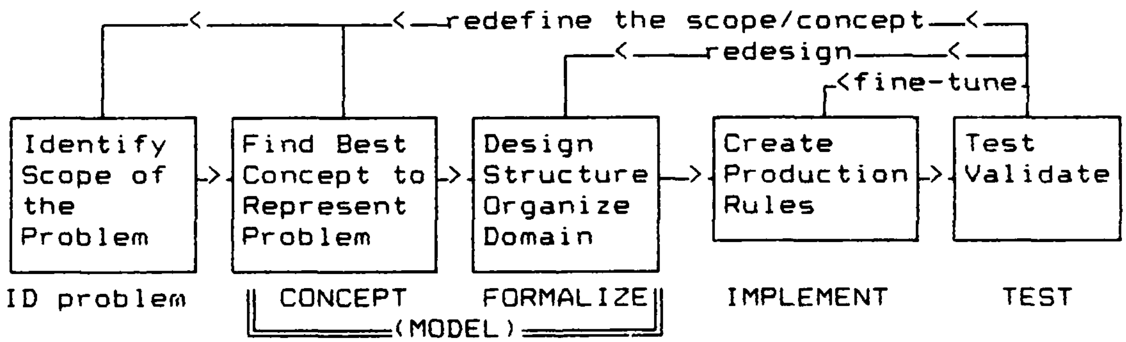


Figure 2. Phases of TAO EXPERT SYSTEM PROTOTYPE Development

B. IDENTIFICATION OF THE PROBLEM SCOPE

In the first phase, most of the time was spent trying to decide how to limit the scope of the problem. Making a tactical decision in a Navy ship at sea, is an extremely complex and involved process. It was absolutely essential to the success of the project, that the problem modeled be clearly defined. The problem involves modeling human thinking in solving complex problems. The actual path to

the possible solution is dependent on the combination of inputs and/or the state of numerous variables at a specific point in time. We have decided to use WAR TIME environment and one ship only (a "BELKNAP" class cruiser) as a representative Navy ship. A scenario involving a limited air and surface engagement, with enemy airborne and surface platforms as opposing force, was deemed representative enough of the TAO tactical environment for the purpose of this prototype. During this stage, several TAO qualified Officers were interviewed and a consensus was obtained which represented the scope of the problem in terms of the TAO environment. The first stage of developing an expert system normally consists of gathering the general information about the domain and the domain expert. In this case however, the author is considered to be an expert in the domain based on the length and the type of his experience and assignments in the Navy. Furthermore, the intended purpose of the unclassified prototype is to demonstrate the feasibility of building an expert system prototype for the TAO tactical environment. The domain is, therefore, limited to a single ship, in time of war, in a small scale air and surface Naval engagement, and it includes surface, air and ESM contacts.

C. PROBLEM REPRESENTATION

In the second phase an effort to develop the best model to represent the TAO decision making process resulted in Figure 3 below.

1. <u>The Kernel</u>

The center box represents the kernel of our model. In the kernel reside the Rules Of Engagement (ROE) and the Policy and the Standing Orders of the ship's Captain. These are "given" values (promulgated by "higher authority") and are the governing constraints. The TAO has no control over

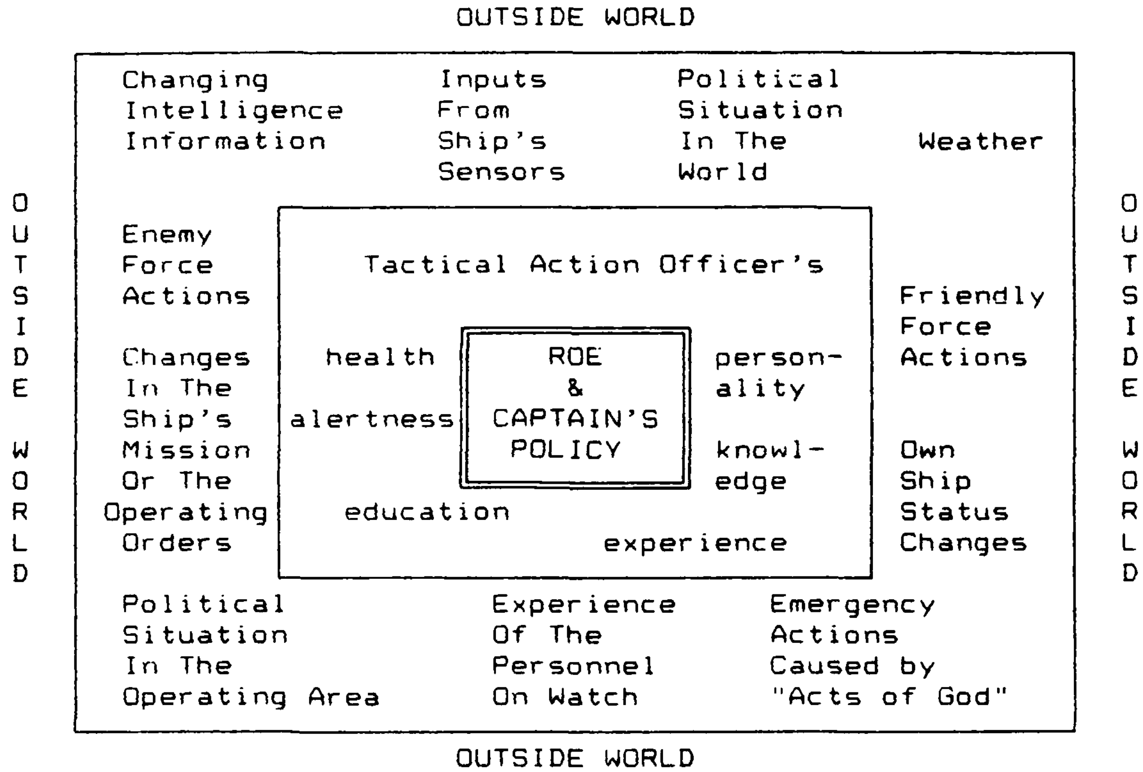


Figure 3. A Model of the TAO Decision Making Process

these rules but must obey them, and use them as a foundation in building his own decision making process. Furthermore, every TAO in the ship is governed by these same constraints, thus the kernel provides a common base for all TAOs in that ship. Note however, that the rules within the kernel may in

fact change at any time, as well as many times, by the "higher authority." The TAO must be able to react to these changes swiftly and correctly.

2. Individual TAO's Input

The second box represents an individual TAO. It represents all the knowledge and experience possessed by a TAO on watch. The TAO establishes that "proprietary" knowledge on the foundation of the knowledge in the kernel. This combined knowledge base is used by the TAO to make necessary decisions.

3. The Environment

The third box represents the immediate environment with which the TAO is interacting. Everything outside the third box is defined as the outside world. The distinction here is one of physical distance from the TAO since the two are often in a "cause and effect" relationship.

The environment is everything except for what is in the second box. The environment includes the kernel, the third ring and the outside world in the methodology of the model.

4. The "Action-Reaction" Process

The TAO is a decision maker in a very dynamic environment. His decision making process is triggered by some change (action or lack of action) in the environment. He, therefore, operates in a reactive mode (relative to his environment). The interfaces between the TAO and the kernel and the TAO and the immediate environment are the critical

areas in view of the "action-reaction" implications of this model. Inputs (catalysts) which cause some action by the TAO, (action could be to do nothing) and the resulting reaction (impact of the TAO's decision) flow across these interfaces.

5. <u>How to Measure a "Reaction"</u>

The actual value of the "reaction" or the TAO's response to the environment, measured on some arbitrary scale of "goodness of TAO decisions" will depend on the combined "worthiness" of the kernel and the second ring discussed above in our model. This value will normally be different for different TAOs even if the "reaction was caused by exactly the same catalysts because of the individual values brought into the knowledge base inside the second box. Recall that the knowledge base which the TAO uses was developed by using the kernel as the foundation and adding on the (individual TAO) knowledge contained in the second box.

The tactical process represented in our model, (see Fig. 3), can be operationally broken down into a hierarchical set of elements and used as a model (Fig. 4 below) to build a knowledge base for a TAO decision making prototype.

D. DESIGN ISSUES

The problem is to simulate, at least in a training environment, the decision making process a TAO goes through to reach tactical decision(s) when his ship is either under

attack or it is about to be attacked. The goal is to develop a prototype expert system program which can analyze the environment (appropriate inputs such as type of contact, contact speed, bearing and range etc.) and determine the appropriate course of action to be taken by the ship. In recognition of the fact that we are trying to emulate the human cognitive process, the prototype being developed will reflect opinions and conclusions drawn upon author's own knowledge and experiences.

1. A Hierarchical Model for Tactical Training

This section proposes a framework to represent knowledge base for building a training system for TAO. Due to the complexity of the tactical domain, including complex environmental inputs (e.g., aspects regarding issues in international political situations, geographical location of the ship, friendly and enemy force structures, etc.) it would be impossible for this present work to consider all the factors influencing the tactical decision making process.

As discussed earlier (Ch I sec. B and D; Ch II sec. B and C; Ch IV sec. C), some limitation of the problem environment must be imposed. Figure 4 presents a model that emphasizes in particular the following determining elements: a limited air and surface engagements, including ESM, and missiles, between own ship and a variety of enemy surface and air platforms.

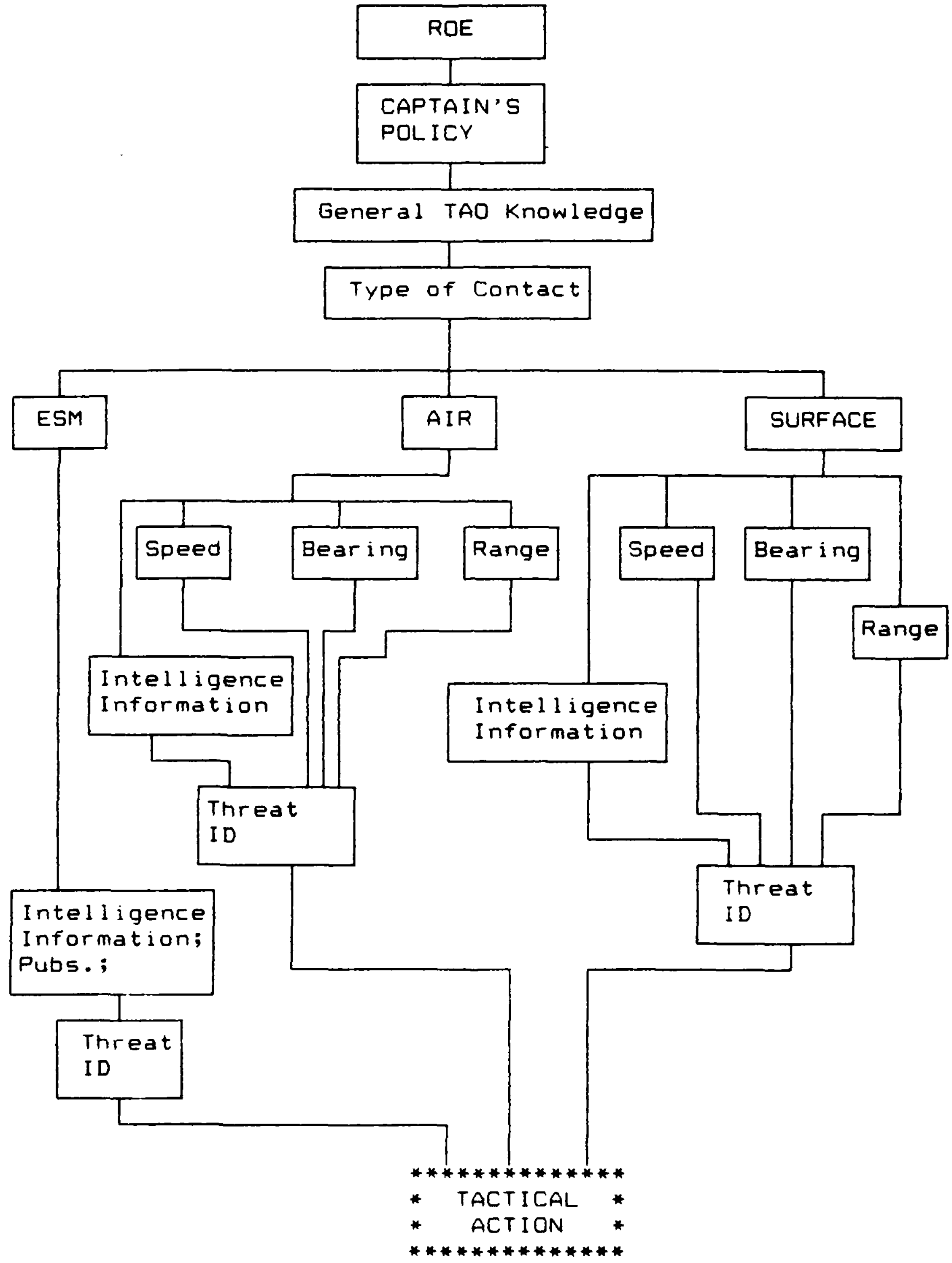


Figure 4. Hierarchy of a TAO EXPERT SYSTEM Knowledge Base

2. Forward-chaining vs. Backward-chaining Process

Several architectures for the knowledge base were considered. The issues of "forward-chaining" vs. "backward-chaining" were addressed with respect to which method is best suited to model the TAO decision process.

It appears that most people use some sort of "forward-chaining" or data driven method in the every day decision making. It seems to be a more common occurrence that a person is faced with a problem to which he has no immediate solution in mind than the one in which he can immediately see the solution. In the first case, the "forward-chaining" method lends itself nicely to the solution process as one proceeds in steps from what he knows in the area of the problem, trying out different approaches until a solution is found. In a "forward chaining" process the designer of an expert system (for a large problem) can break up the problem into smaller subproblems. He can then make the results of one subproblem the presumptions of another. In this fashion the designer of an expert system can work his way to the desired goal.

Hayes-Roth [Ref. 4: pp. 267] provides an excellent description of the goal oriented "backward-chaining" process. In this approach, the system initially possesses a set of candidate general solutions, each of which it considers in turn. For each candidate solution, it seeks knowledge base rules that can achieve that solution and attempts to find

data for each that satisfy the antecedent condition of the rule. If that doesn't work, it will attempt to find other rules that can infer or achieve the necessary conditions. Failing that, it may query the end user to establish the prerequisites.

3. Selection of the Architecture

The required "knowledge base" for the TAO EXPERT SYSTEM MODEL, did not seem to fit well into the existing, sequential process, the "input-process-output" model common in computer programs. We were trying to model human, cognitive thinking process and most people "jump" around in their thought process and consider many different, often apparently unrelated topics in arriving at a decision. The scope of the problem (defending a ship at sea in time of war), even within the sharply defined boundaries as used in the scenario for our model, remains a very complex task. For example, starting from an ESM detection of an air target to the final action of firing CHAFF to pull the missile off course, requires that many different steps be taken and a large amount of tactical and statistical data be reviewed by the TAO before a decision can be made. With a very large number of possible alternatives for each situation which could be considered by the TAO, and the time available to arrive at a "good" decision being very short in most instances, we needed a high-level architecture which allowed an efficient and fast method of "pruning" those possible

search trees which were not as likely to produce "good" solutions in the shortest time.

In the TAO environment under study for our model, we chose the "backward-chaining" method based on the following analyses. The TAO's purpose is to determine and execute solutions given a specific problem (such as an inbound missile). The goal is (almost always) very clearly defined. In the case of an inbound missile the goal could be to shoot it down or to pull it off its intended target and have it impact in an area where it will not do any damage (or cause a minimal amount of damage) to the TAO's own ship or other friendly units. The goal could be any single one, or any combination of those mentioned above depending on the ship's operating orders and the rules of engagement.

In addition, the TAO possesses other knowledge which helps him to make decisions concerning possible solutions to the problem at hand. In other words, this situation appears to match the requirements for a "backward-chaining" method of problem solving. The goal is clearly defined and the "candidate" solutions are available at the outset.

4. Optimization of the Process of the Knowledge Base Acquisition

During the design of the knowledge base, we were aware of the "backward-chaining" characteristics of our "inference engine." We start from an action which is required in order to accomplish the objective and then

construct a backward chain of events which would most likely lead to that particular action in the end.

The hierarchy of the knowledge base is implemented in the following manner: At the start of the program, the expert system is given certain knowledge facts by the designer of the program. When the expert program needs additional data from the user, it will ask for the type of data which will allow it to make good and useful decisions and or recommendation.

The designer of the program must therefore structure such (program provided) input choice lists, both in the contents of the potential choices and in the order in which these input lists will appear during the interaction with the user. The interaction with the user must be intelligent and sequential and of course, must be at the user's knowledge level as well.

To improve the efficiency (speed) of the expert program, the knowledge base was structured in a manner suitable for the heuristic search methods employed. The actual steps in the procedure have some resemblance to "top down" method in traditional programming, combined with the "in-depth" search of the particular "branch" of the preplanned (by the program designer) list of possible occurrences. The point here is that the program "knows" when it is at some sort of "crossroads" or a junction and uses the

rules in its knowledge base to determine which "branch" to pursue further.

5. <u>Selection of the Development Tool</u>

During this phase, a review of available programming languages and expert system development tools was conducted. Such "traditional" AI languages as PROLOG and LISP were looked at as well as the emerging languages SMALLTALK-80, MPROLOG, OPS5, and OPS83. In addition, software tools grouped under the general name of "expert system development tools" such as EXSYS, EXPERT EASE, EXPERT CHOICE, KES, and RULEMASTER were examined.

We chose to use an expert system development tool in order to implement our own expert system prototype. We have decided to use EXSYS, which is one of several expert system development tools currently available on the market. EXSYS uses "production rules" for knowledge representation. The reason we selected a "production rules" system are [Ref. 6]:

1. They have simple format.
2. They allow a simple control structure.
3. They allow a reasoning process which appears natural.
4. The system can examine its own knowledge.
5. If these rules are independent, then additional rules can be added to increase competency.

EXSYS is an expert system in its own right, written in C language and is one of several emerging expert system development languages (more accurately described as "tools"). EXSYS was chosen because it uses English like commands and

has good user-interface capabilities. Additionally, it offers a good editing capability which was considered to be important during the on-line prototype development. EXSYS was also immediately available and inexpensive ($295) and there were other people who were interested in using EXSYS to build other expert systems. This project was to be an application study of EXSYS as a by product of developing the Expert System training prototype for TAO.

6. System/user Compatibility

One of the design issues dealt with the question of how well should the TAO expert system fit the user, (individual TAO) as well as the domain. It is a common industry goal to have the software fit the user, or to be easily modifiable to the specific user requirements. Due to the "heuristic" nature of the expert system production rules, and the requirement to keep the model unclassified, it was decided to build this prototype model based on general principles and common knowledge methods of TAO decision making. Modifications of the model to suit individual TAO can be accomplished with some changes in the production rules.

7. Ease of the Knowledge Base Maintenance

As previously discussed, the TAO must consider many factors including the weather and the intelligence information which are "perishable" information. Such information has to be entered into the knowledge base as

changes occur. The system must be designed for ease of operation and knowledge base updates. Such knowledge base maintenance can be performed by modifying the production rule(s) effected. However, the "ripple" effect must be kept to a minimum. A separate data base (from the knowledge base used in the production rules) may have to be created to contain such "perishable" information.

V. THE TAO EXPERT SYSTEM PROTOTYPE IMPLEMENTATION

A. THE MEASURE OF CERTAINTY

A "backward-chaining" hierarchy with a "production rule" approach to building the knowledge base was chosen for this prototype. Each rule and intermediate conclusion in "knowledge based" systems usually possesses a measure of certainty (the certainty factor). As the system draws new inferences, it calculates their certainty factors. A scale of 0-10 was determined to be appropriate for this application. A "0" represents an absolute "no" and a "10" represents an absolute "yes" with the remainder of the scale being equally divided. Thus, an event with the value of 7/10 is more likely to happen then an event with a value of 3/10. The domain was limited to air, surface, and ESM engagements only.

B. IMPLEMENTATION OF THE PRODUCTION RULES HIERARCHY

During this phase, we collected specific TAO knowledge in the form of production rules. Specifically, "IF-THEN" rules which require that specific conditions be met before the rule being examined and its accompanying conditions are accepted by the system as true. In the TAO knowledge area, there may well be several possible alternatives to achieving the desired goal. These alternatives may all require a common piece of information. Obtaining this information may require a large amount of inference procedures and condition testing.

The system may have to ask the user for the information it can not obtain from its own resources. The interaction with the user must be at the appropriate level to meet the user's needs. The queries generated by the expert system and the order in which these queries are generated is of critical importance and are dependent on the structure of the knowledge base.

1. Imparting Knowledge to the Knowledge Base

The prototype we are developing is a "knowledge based" system. It requires a large accumulation of knowledge in the domain of naval tactical decision making. Using this knowledge, the system should develop a high level support (including recommendations as to specific actions to be taken) to the TAO in tactical decision making.

We would like to point out that all the preplanned responses for the events covered by the prototype, will be contained in a set of production rules. The production rules form the knowledge base of the prototype. They are in the form of "IF-THEN" pairs where the validity of the "IF" part or condition is tested and if found to be "true", "THEN" part is accepted to be true. The "inference method" in our prototype involves obtaining the data from an outside source (in this prototype the outside source is the user), searching the text file of rules in the knowledge base and matching the input against the stored rules and terms. The system uses "backward-chaining" which allows the program to derive

information from the rules already in its knowledge base. If the user wants to find out how the system arrived at a particular decision, he can enter a simple, menu driven command, and the system can explain how it arrived at its conclusion.

For example:

The user is presented with a choice:

type of contact is
1. air contact
2. surface contact
3. ESM contact

If the user enters 1 (air contact), the system "knows" that an air contact could be a MISSILE, a TARGETING OR RECONNAISSANCE AIRCRAFT, or a MISSILE FIRING AIRCRAFT. It will try to determine what type of air contact it was given by asking the user about the air contact's speed. Based on the speed information, the system will start to "define" the air contact it is working. The system will then try to determine the danger level this contact presents to the user. It "knows", for example that a missile with a constant bearing decreasing range is an emergency situation and requires immediate and decisive action while an orbiting reconnaissance aircraft, outside the range of the user's weapons requires only a careful monitoring and no overt action. Depending on the bearing and range obtained from the knowledge it already possesses or by asking the user, the system will search its rule base to determine the most appropriate action(s) under the circumstances. It will

attempt to provide some type of recommended solution even if the data is incomplete. The strength of the system lies in its ability to come up with some recommendations based on the partial information which is available to it.

An example rule which the system is working may be as follows:

IF	threat is a MISSILE	
	and contact movement is inbound or closing	
THEN	engage with PHALANX	-probability= 10/10
	and fire CHAFF	-probability= 10/10
	and engage with 5/54	-probability= 6/10

2. Efficiency of the Knowledge Base

The rule base in our model was "engineered" to provide for early "pruning" of the unlikely solution paths to the problem. This is an important point in the expert systems and it is really only the designer of the system who must address it. The user of the system derives the benefits in terms of a faster, more efficient expert program and is not at all concerned about the method which was used to "prune" the less promising search paths.

For example, the overall objective is to prevent damage to the ship; an action may be - TAO fires CHAFF. We build a set of "IF-THEN" rules which examine possible (preconceived) situations which may cause the TAO to fire CHAFF. We then provide more rules which examine, from a different perspective perhaps, other rules already in existence for

validity checks and cross-checks. We must also design other rules which could, by examining data and information already "known" to the knowledge base, determine the validity of a new rule being worked by the expert program. And finally, we must design the order and the type of questions the expert program will ask the user during the user/system interaction.

VI. AN EXPERT TUTORING SYSTEM FOR TACTICAL TRAINING

A. SYSTEM CHARACTERISTICS

The expert system prototype for tactical training, was built using EXSYS expert system development tool. The prototype system runs on IBM PC and compatible computers with 256K of memory or greater. The EXSYS generator requires 192K of memory and the remaining memory is used by the production rules of the prototype. Each rule can have up to 126 conditions in its IF part and up to 126 conditions plus choices in its THEN part. A condition is simply a statement of fact (or potential fact). It is simply a sentence which may be true or false. Each condition is made up of two parts, a qualifier and one or more values. The qualifier is usually the part of the condition up to and including the verb. The values are the possible completions of the sentence started by the qualifier. For example, in the condition "The speed of the air contact is very fast," the qualifier part is "the speed of the air contact is" and the value part is "very fast," Choices are all the possible solutions to the problem (included in the knowledge base) among which the expert system will decide. For example, in the following production rule "IF missile is inbound THEN engage with PHALANX," the choice is "engage with PHALANX" (as opposed to engage with 5/54). EXSYS manual [Ref. 6] provides the following information:

If production rules with an average of about 8 total conditions and choices are used, then about 700 rules can be created in a PC with 256K memory (about 5000 rules in a PC with 640K of random access memory).

B. HOW DOES IT WORK?

The actual procedure the TAO EXPERT SYSTEM PROTOTYPE goes through is as follows. At the start of the program, all of the rules in the knowledge base are read. During this process, some of the rules are used to infer other rules. Some rules are used to test the validity of the conditions in other rules. If any rules are found, in which all of the "IF" conditions are validated to be true during this initial reading process, the program stores this knowledge and uses it later on. When the initial reading of the rules is completed the program goes back to the beginning of the knowledge base and examines the first "IF" condition of the first rule which it doesn't already know to be true. It is at this point that the program will begin the interaction with the user by asking the user for inputs. The program will "guide" the user regarding which inputs the user can provide. It does this by presenting the user with a list of potential inputs, and by allowing the user to enter any individual one, or any combination of the items on the list but no other. If the user tries to enter anything other than the items or combination of items offered by the program, the program will keep asking for the valid input.

After all, its entire reason for being is to provide the user with useful expert advice or recommendations. The expert program will examine the data provided by the user against the rules in its knowledge base. The rules in the knowledge base are set up in such a fashion that based on what the system knows to be true at the point of a "branch" in its hierarchy, it will take the "branch" which offers a possibility of a potential solution and will stop pursuing the remaining "branch" or "branches". For example: when the expert program asks the user for the type of contact he has (by providing the user with a choice of air, surface and ESM contacts) the user can pick any one of them or any combination of them. For simplicity of explanation, let's say the user enters an air contact. The expert program will continue to examine only the rules which have some connection with the air contact and will no longer look at the rules which deal strictly with surface or ESM contacts. The interaction with the user will reflect this action as well since the user will be asked to provide data relevant only to the air contact. The designer of the program must build this ability in the knowledge base when it is being constructed.

We are dealing with human knowledge acquisition and a prototype (and a limited) model of a human thinking process. There may be several ways in which a decision to fire CHAFF may be reached by a TAO given the same set of input conditions. We realize this and do not claim that ours is

the only or the best way. Our purpose was to demonstrate a method to develop an expert system in the TAO tactical environment and to encourage others to experiment further and improve or build larger and better systems in this field.

The prototype developed during this thesis uses 63 production rules which are listed in Appendix B.

C. TEST AND VALIDATION

Given the scope and time constraints of this work, this phase is excluded. The accomplishment of this phase includes testing of the prototype by several persons, including the members of the faculty and the students who are TAO qualified, for performance and validity checks. A better test would be to use the prototype in a real life training environment.

D. DEVELOPMENT STATISTICS

What follows are figures (in manhours) which indicate the amount of time expended on this project by category:

1. Identify the scope of the problem: 19
2. Find the "best" way to represent the problem: 40
3. Learning the development program (tool): 14
4. Creation of knowledge base: 128
5. Testing and validation: This is an ongoing effort.

Several problems were encountered during this project. The EXSYS development tool is not very easy to use (the manual does not reveal the real complexity of using EXSYS to

build expert systems). In addition, many iterations of the knowledge base were completed, primarily due to our tendency to go off in pursuit of an interesting idea and forget about the bounds of the problem. Combining the positions of the "knowledge engineer" and the "domain expert" seemed to be counterproductive at times.

VII. LESSONS LEARNED/RECOMMENDATIONS FOR FUTURE STUDY

A. THE TAO EXPERT SYSTEM AS A COMPUTER-AIDED-INSTRUCTION

This project demonstrated the need for expert systems in the tactical decision making area in a small scale naval engagement. Furthermore, it has been demonstrated that the technology exists and is readily available, at least at the level suitable for training inexperienced Officers. It clearly demonstrates a new way to transfer the knowledge and "know-how" acquired over the years by "experts" to the inexperienced personnel, without the requirement for the "expert" to be physically present during the training. This has tremendous impact in the Navy where the experienced personnel are regularly and often transferred to another command and the operating ships must continually train their own TAOs. An expert system of the type developed and demonstrated in this thesis can be reproduced easily and at a nominal cost and distributed to every operating command which has junior Officers who need the TAO training. In fact, if the expert system was comprehensive enough, many a senior Officer could benefit with a little refresher. The additional advantage for this system is its user friendliness. The student can proceed at his/her own pace and the system will provide explanations about what it is doing and why. The student can have the benefit of a large

body of experience which went into building the expert system without tying up the expensive (expert personnel) resources.

B. FROM COMPUTER-AIDED-INSTRUCTION TO REAL-TIME APPLICATION

In order to use an expert system such as the prototype described in this thesis in real time (instead of in the training mode) several issues must be addressed. First is the speed with which the expert system needs to come up with acceptable recommendations. The second issue deals with the movement of data and information between various watchstations and the TAO. The third issue deals with automated data inputs from ship's sensors to the expert system.

1. Timeliness of Decisions

The current version of the prototype is not designed to respond to the user within the requirements of real-time constraints in reaction time. However, a properly designed knowledge base and an efficient program can be produced to meet or exceed the speed of a human expert in the domain with added assurances that the threat characteristics have been compared with the right tables and the threat evaluations are correct based on the inputs provided.

2. Automated Information Flow to the TAO

In most cases today, the TAO receives the information he needs to make tactical decisions, over a loudspeaker, or a sound-powered phone. In the later case the information comes sequentially and may be late or drowned/suppressed due to

another transmission being broadcasted at the time, or it may need to be repeated to the TAO. A lot of time is lost during this information gathering stage. Another source of information are the visual displays, both the manual "grease pencil" boards and the various radar or other instrument screens. It is our contention that a direct, electronic input using distributed and on-line devices such as specifically designed touch-keypad could greatly speed up the input of data to the knowledge based expert system and the TAO display station. Such I/O devices could replace the present communication methods (usually sound powered phones) between the sensor stations and the TAO. The added benefit which would result from an automated system would be the reduced level of noise in CIC and significant reduction in the TAO information overload. With respect to our prototype,the present interaction between the expert system and the user would no longer be required since the system would get its data directly from the sensor operators. The TAO would simply monitor the tactical situation, do his own figuring and decision making and than will be able to compare his conclusions or intended actions against those recommended by the expert system. Again, we believe that this area is ready to be explored and it holds a lot of promise. It is, however a subject which should follow the work done in this study as it appears to be the logical extension of the same idea.

3. Expert System / Ship's Sensors Direct Interfaces

Another area which needs further study is the interface between an expert system such as the prototype presented here and the real time sensors in a Navy ship such as various radars, sonar, and ESM equipment. If a "good" interface can be designed such that the data obtained at the sensor, for example the bearing and range of a contact on an air search radar, can be fed directly to the knowledge base, the recommendations provided by the expert system should be acceptable for real time utilization. We believe that such interfaces are technologically feasible and recommend a future study of design and potential steps to implement such an interface be conducted as a thesis topic.

VIII. CONCLUSION

A. SUMMARY OF RESULTS

We have demonstrated the feasibility of developing a knowledge based expert system in the Tactical Action Officer's decision making domain. Although the scope of the domain captured in the prototype is narrow, the architecture employed can be essentially retained while extending its domain knowledge in the future. The prototype has been tested only by the author and a limited number of TAO qualified Officers and professors at the Naval Postgraduate School, Monterey, California. Prototype is yet to be tested under field conditions. However, the prototype demonstrates the effort is feasible and an expert system in this particular domain would be highly useful.

B. THE RESPONSIBILITY ISSUE

If such an expert system was installed and in widespread use in the fleet, who should be responsible for its actions and decisions? The ship's Captain? The TAO who did not override the system?

What are the dangers of the TAO's becoming complacent and too dependent on the expert system to make all their decisions?

These are but a few questions which require careful and diligent study. These issues should be addressed since they

will have a tremendous impact on the acceptance of computerized systems in the fleet.

APPENDIX A

HOW TO RUN THE TAO PROTOTYPE

1. Getting Started

Before you start you should have the TAO EXPERT SYSTEM PROTOTYPE diskette, and an IBM PC or a compatible with at least 256K of random access memory. If the PC is already on and A> is displayed place the TAO EXPERT SYSTEM diskette in drive A and type EXSYS <enter>. A copy of the prototype system diskette can be obtained by writing to the Superintendent, Naval Postgraduate School, code 043, Monterey, California 93943-5004 via the Defense Technical Information Center, Cameron Station, Alexandria, Virginia 22304-6145. If the PC is not on, place the TAO EXPERT SYSTEM diskette in drive A and turn on the PC. The TAO EXPERT SYSTEM diskette must be in the default drive, the one indicated with the DOS prompt. Enter the correct date and time when prompted. When A> appears type EXSYS <enter>. When EXSYS logo appears you will be asked for the file name; type TAO <enter>. The system will load and you will be asked if you wish instructions on how to run EXSYS. If this is your first exposure to expert systems it is recommended that you review the instructions on how the system works (type y <enter>). If you are experienced with this type of systems, you may choose not to look at the instructions (type N <enter> or just hit the <enter> key). The next major

selection area is to decide if you want to have the rules (which are being worked by the system) displayed or not. If the rules are displayed, it will take longer to arrive at the recommendation stage (solution(s)) of the problem, however you will be able to follow what the system is doing. Regardless of which option you select, you will still be able to see at any time, the rules which the system is working by typing WHY <enter>.

The system will always display a menu at the bottom of the screen.

2. A Training Session

The system will display the subject of the expert system and the author's name. You will then be shown information which describes the TAO EXPERT SYSTEM PROTOTYPE scenario and sets the parameters for the training session.

The system will start asking you questions relevant to the tactical environment within the boundaries of the scenario defined in the introduction. This is how the system obtains the data needed to make a decision. You will be presented with multiple choice questions. Enter the number or numbers of the choice(s) which is most appropriate at that time. If more than one number is selected, use commas to separate the entries. When the system has obtained enough data to determine that all the IF conditions in the rule being worked are true, it will display the rule (unless you have opted not to have the rules displayed as they are used).

When the system has enough information to make some recommendations it will display its results. It will give you the opportunity to make your own decisions and will not display its results until prompted by you to do so. It will display its recommendations in order of "best to worst" and will also display the "value" of each recommendation using the "0 to 10" scale. In this case the value of 0 means that action will absolutely not be done, and the value of 10 means the action will definitely be done. The values between 1 and 9 indicate the degree of certainty (and order) with which the action will be carried out, with 1 meaning probably not and 9 meaning almost assuredly, and with minimal delay. In this manner, you can see the CONFIDENCE of the recommended solutions to the particular tactical situation you were working on. At this point, you can ask the system how a particular conclusion/recommendation was reached by entering the line number for that recommendation. The system will display all of the rules it used to determine the particular conclusion/recommendation.

3. Analysis Phase

The system allows you to analyze the effect of different data inputs on the final list of recommendations. You can change one or more of the inputs you provided in response to the system questions while holding the other inputs constant and rerun the new data to see what effects these changes have on the final outcome. You can store the

results from several "runs" to be compared at a later time. The step by step instructions on how to change and rerun the data is provided by the menu. You can also make a printed copy of the results of a run, including the data you provided during the interaction with the system. Finally, to exit the program, enter "D" (for "done"). You will then be given the option of running the program again or not.

APPENDIX B

PRODUCTION RULES USED IN THE EXPERT SYSTEM PROTOTYPE

Subject:

A prototype of Expert System Tactical Action Officer (TAO) decision making process during a small scale naval engagement.

Starting text:

This is a simple prototype of an expert system in the TAO environment. For the sake of simplicity and to keep this prototype UNCLASSIFIED, fictitious names are used for the weapon systems.

Also, the following assumptions are made:

1. You are on a "BELKNAP" cruiser.
2. These weapon systems are available to you: HARPOON; TERRIER; ASROC; 5/54; PHALANX; CHAFF.
3. Your own emitters are: SPS-10; SPS-40; SPS-43; SPS-48D; SPS-49; SPS-26BX; SPS-53A.
4. You are in a WARTIME environment.
5. You are in CONDITION I (GQ) and you are the TAO on watch.
6. You are steaming independently.
7. Intelligence information indicates possible enemy air and surface platforms are in the area. However, there is some civilian shipping and aircraft traffic in your operating area as well.
8. Your mission is to: defend own ship; identify contacts; engage the enemy.

The program will attempt to make decisions about the events which are presented to it. It will ask you for information which it is not able to determine from the knowledge it already has. Please enter the most appropriate choice. If more than one choice is entered, use commas to separate the entries.

Ending text:

These are recommendations only. The TAO is still required to make the final decision.

The program uses all applicable rules in data derivations.

PRODUCTION RULES:

RULE NUMBER: 1

IF:	type of contact is	ESM contact
	and you hold	no surface contact
	and you hold	no air contact
THEN:	determine type of threat	-probability= 8/10
	and range to the threat is	unknown
	and contact movement is	unknown

NOTE: 1. Your actions will depend on whether or not you intend to engage the enemy or to get away from him based on your mission requirements.

REFERENCE:
This information can be retrieved from a classified program which is not included in this model.

RULE NUMBER: 2

IF:	threat is	a MISSILE
	and contact movement is	inbound or closing
THEN:	engage with PHALANX	-probability= 10/10
	and fire CHAFF	-probability= 10/10
	and engage with 5/54	-probability= 6/10

NOTE: 1. We are only interested in inbound missiles.

RULE NUMBER: 3

IF:	threat is	a MISSILE
	and contact movement is	outbound or opening
THEN:	do nothing-missile is outbound	-probability= 7/10

NOTE: 1. Outbound missile is no longer a threat to you and you are not protecting any friendlies.

RULE NUMBER: 4

IF:	type of contact is	air contact
	and air contact speed is	very fast
THEN:	threat is	a MISSILE
	and it is	an enemy

NOTE: 1. Very fast speed represents a missile in this model.

RULE NUMBER: 5

IF: 5 consecutive bearings are the same
and each consecutive range is smaller

THEN: contact movement is inbound

RULE NUMBER: 6

IF: type of contact is ESM contact
and type of contact is air contact
and air contact speed is unknown

THEN: maintain increased state of alert until
situation calls for more definitive action
-probability= 9/10

RULE NUMBER: 7

IF: threat is an A/C with missiles
and contact movement is inbound or closing
and it is an enemy

THEN: engage with TERRIER -probability= 9/10
engage with 5/54 -probability= 6/10

NOTE: 1. 5/54 is limited in range

RULE NUMBER: 8

IF: threat is an A/C with missiles
and contact movement is holding station or orbiting
and it is an enemy or an unknown

THEN: be on alert for "splits" from the contact if it is
within the range of its missiles -probability= 10/10
and alert lookouts -probability= 8/10
and alert EW's of the bearing -probability= 7/10
and continue to monitor its position and ESM
-probability= 10/10

NOTE: 1. If he is within the range of his air to surface missiles you must be prepared to fire your own missiles at him and to use PHALANX and CHAFF in your own defense.

RULE NUMBER: 9

IF: threat is an A/C with missiles
and contact movement is outbound or opening

THEN: continue to monitor its position and ESM
-probability= 10/10
and be on alert for "splits" from the contact if it is within the range of its missiles
-probability= 10/10

RULE NUMBER: 10

IF: type of contact is air contact
and air contact speed is fast
and you detect MISSILE A/C ESM

THEN: threat is an A/C with missiles
and it is an enemy

NOTE: 1. Fast speed represents A/C with missiles.
2. MISSILE A/C ESM represents an enemy missile firing A/C.

RULE NUMBER: 11

IF: 5 consecutive bearings are not the same
and each consecutive range is smaller

THEN: contact movement is closing

RULE NUMBER: 12

IF: threat is a reconn A/C
and contact movement is holding station or orbiting or opening

THEN: continue to monitor its position and ESM
-probability= 9/10
alert lookouts -probability= 8/10

RULE NUMBER: 13

IF: threat is a reconn A/C
and contact movement is inbound or closing

THEN: continue to monitor its position and ESM
-probability= 10/10
and alert lookouts -probability= 9/10

RULE NUMBER: 14

IF:	type of contact is	air contact
	and air contact speed is	slow
	and you detect	TARGETING A/C ESM
THEN:	threat is	a reconn A/C
	and it is	an enemy

NOTE: 1. Slow speed represents reconnaissance A/C or it could be a commercial flight.
2. TARGETING A/C ESM represents an enemy targeting or reconnaissance A/C.

RULE NUMBER: 15

IF:	5 consecutive bearings are	not the same
	and each consecutive range is same	
THEN:	contact movement is	orbiting

RULE NUMBER: 16

IF:	5 consecutive bearings are	not the same
	and each consecutive range is larger	
THEN:	contact movement is	opening

RULE NUMBER: 17

IF:	5 consecutive bearings are	the same
	and each consecutive range is same	
THEN:	contact movement is	holding station

RULE NUMBER: 18

IF:	5 consecutive bearings are	the same
	and each consecutive range is larger	
THEN:	contact movement is	outbound

RULE NUMBER: 19

IF:	you detect	MISSILEHOMING ESM
THEN:	threat is	a MISSILE

NOTE: 1. MISSILEHOMING ESM represents an enemy missile.

RULE NUMBER: 20

IF:	you detect	TARGETING A/C ESM
THEN:	threat is	a reconn A/C

NOTE: 1. TARGETING A/C ESM represents an enemy targeting or reconnaissance A/C.

RULE NUMBER: 21

IF:	you detect	a MISSILE A/C ESM
THEN:	threat is	an A/C with missiles

NOTE: 1. MISSILE A/C ESM represents an enemy missile firing A/C.

RULE NUMBER: 22

IF:	threat is	a MISSILE SHIP
	and contact movement is	inbound or closing
	and it is	an enemy or an unknown

THEN: be on alert for "splits" from the contact if it is within the range of its missiles -probability= 10/10
and determine its CPA to you -probability= 10/10
and alert lookouts -probability= 8/10
and alert EW's of the bearing -probability= 9/10
and continue to monitor its position and ESM -probability= 10/10

RULE NUMBER: 23

IF:	threat is	a MISSILE SHIP
	and contact movement is	holding station or outbound or opening
	and it is	an enemy or an unknown

THEN: continue to monitor its position and ESM -probability= 10/10
and be on alert for "splits" from the contact if it is within the range of its missile-probability=10/10
and alert lookouts -probability= 6/10

RULE NUMBER: 24

IF:	type of contact is	ESM contact
	and you detect	MISSILESHIP ESM
THEN:	threat is	a MISSILE SHIP
	and it is	an enemy

RULE NUMBER: 25

IF:	type of contact is	surface contact
	and you detect	MISSILESHIP ESM
THEN:	threat is	a MISSILE SHIP
	and it is	an enemy

NOTE: 1. MISSILESHIP ESM represents enemy ships with surface to surface missiles.

RULE NUMBER: 26

IF:	threat is	a GUN SHIP
	and contact movement is	inbound or closing
THEN:	determine its CPA to you	-probability= 10/10
	and alert lookouts	-probability= 9/10
	and alert EW's of the bearing	-probability= 7/10
	and continue to monitor its position and ESM	-probability= 10/10

NOTE: 1. EW's should already be alerted to the contact at this point.

RULE NUMBER: 27

IF:	threat is	a GUN SHIP
	and contact movement is	holding station
THEN:	alert EW's of the bearing	-probability= 7/10
	and alert lookouts	-probability= 9/10
	and continue to monitor its position and ESM	-probability= 10/10
	and alter your course and speed to bring the enemy inside the range of your weapons	-probability= 8/10
	and alter your course and speed to move out of the range of enemy's weapons	-probability= 9/10

NOTE: 1. Your actions will depend on whether or not you intend to attack this contact.

RULE NUMBER: 28

IF:	type of contact is	ESM contact
	and you detect	GUNSHIP ESM
THEN:	threat is	a GUN SHIP
	and it is	an enemy

RULE NUMBER: 29

IF:	type of contact is	surface contact
	and you detect	GUNSHIP ESM
THEN:	threat is	a GUN SHIP
	and it is	an enemy

NOTE: 1. GUNSHIP ESM represent an enemy ship without surface to surface missiles.

RULE NUMBER: 30

IF:	it is	an unknown
THEN:	continue to monitor its position and ESM	-probability= 10/10
	determine its speed	-probability= 9/10
	determine its CPA to you	-probability= 9/10

RULE NUMBER: 31

IF:	type of contact is	air contact or surface contact
	and you detect	no ESM
	and you have	no visual ID
THEN:	it is	an unknown

RULE NUMBER: 32

IF:	you are	inside the range of enemy's weapon(s)
	and enemy is	outside the range of your weapon(s)
THEN:	alter your course and speed to move out of the range of enemy's weapon(s)	-probability= 5/10
	alter your course and speed to bring the enemy inside the range of your weapon(s)	-probability= 5/10
	continue to monitor its position and ESM	-probability= 10/10

NOTE: 1. Your actions will depend on whether or not you intend to attack the enemy.

RULE NUMBER: 33

IF: you are inside the range of enemy's weapon(s)
and enemy is inside the range of your weapon(s)
and threat is an A/C with missiles or a reconn A/C

THEN: engage with TERRIER -probability= 10/10
engage with 5/54 -probability= 5/10

RULE NUMBER: 34

IF: you are inside the range of enemy's weapon(s)
and enemy is inside the range of your weapon(s)
and threat is a MISSILE SHIP or a GUN SHIP

THEN: engage with HARPOON -probability= 9/10
engage with 5/54 -probability= 8/10

NOTE: 1. Depending on the actual range to the target and the quality of the targeting information you may or may not use HARPOON.

RULE NUMBER: 35

IF: you are outside the range of enemy's weapon(s)
and enemy is inside the range of your weapon(s)
and threat is an A/C with missiles or a reconn A/C

THEN: engage with TERRIER -probability= 10/10

RULE NUMBER: 36

IF: you are outside the range of enemy's weapon(s)
and enemy is inside the range of your weapon(s)
and threat is a MISSILE SHIP or a GUN SHIP or an AGI

THEN: engage with HARPOON -probability= 9/10
engage with 5/54 -probability= 8/10

NOTE: 1. It depends on the actual range to the contact, the quality of the targeting information and the presence/absence of other surface contacts in the area.

RULE NUMBER: 37

IF: you are outside the range of enemy's weapon(s)
and enemy is outside the range of your weapon(s)

THEN: continue to monitor its position and ESM -probability= 10/10
alter your course and speed to bring the enemy inside the range of your weapon(s)-probability= 5/10

NOTE: 1. Your actions will depend on your mission requirements at the time.

RULE NUMBER: 38

IF: range to the threat is unknown

THEN: you are outside the range of enemy's weapon(s)
and enemy is outside the range of your weapon(s)

RULE NUMBER: 39

IF: range to the threat is close

THEN: you are inside the range of enemy's weapon(s)
and enemy is inside the range of your weapon(s)

RULE NUMBER: 40

IF: range to the threat is medium
and threat is an A/C with missiles

THEN: you are inside the range of enemy's weapon(s)
and enemy is inside the range of your weapon(s)

RULE NUMBER: 41

IF: range to the threat is medium
and threat is a reconn A/C

THEN: you are outside the range of enemy's weapon(s)
and enemy is inside the range of your weapon(s)

RULE NUMBER: 42

IF: range to the threat is medium
and threat is a MISSILE SHIP

THEN: you are inside the range of enemy's weapon(s)
and enemy is inside the range of your weapon(s)

RULE NUMBER: 43

IF: range to the threat is medium
and threat is a GUN SHIP

THEN: you are inside the range of enemy's weapon(s)
and enemy is inside the range of your weapon(s)

RULE NUMBER: 44

IF: range to the threat is medium
and threat is an AGI

THEN: you are outside the range of enemy's weapon(s)
and enemy is inside the range of your weapon(s)

RULE NUMBER: 45

IF: range to the threat is far
and threat is an A/C with missiles

THEN: you are inside the range of enemy's weapon(s)
and enemy is inside the range of your weapon(s)

RULE NUMBER: 46

IF: range to the threat is far
and threat is a reconn A/C

THEN: you are outside the range of enemy's weapon(s)
and enemy is inside the range of your weapon(s)

RULE NUMBER: 47

IF: range to the threat is far
and threat is a MISSILE SHIP

THEN: you are inside the range of enemy's weapon(s)
and enemy is inside the range of your weapon(s)

RULE NUMBER: 48

IF: range to the threat is far
and threat is a GUN SHIP

THEN: you are outside the range of enemy's weapon(s)
and enemy is inside the range of your weapon(s)

RULE NUMBER: 49

IF: range to the threat is far
and threat is an AGI

THEN: you are outside the range of enemy's weapon(s)
and enemy is inside the range of your weapon(s)

RULE NUMBER: 50

IF: range to the threat is very far
and threat is an A/C with missiles

THEN: you are outside the range of enemy's weapon(s)
and enemy is outside the range of your weapon(s)

RULE NUMBER: 51

IF: range to the threat is very far
and threat is a reconn A/C

THEN: you are outside the range of enemy's weapon(s)
and enemy is outside the range of your weapon(s)

RULE NUMBER: 52

IF: range to the threat is very far
and threat is a MISSILE SHIP

THEN: you are inside the range of enemy's weapon(s)
and enemy is outside the range of your weapon(s)

RULE NUMBER: 53

IF: range to the threat is very far
and threat is a GUN SHIP

THEN: you are outside the range of enemy's weapon(s)
and enemy is outside the range of your weapon(s)

RULE NUMBER: 54

IF: range to the threat is very far
and threat is an AGI

THEN: you are outside the range of enemy's weapon(s)
and enemy is outside the range of your weapon(s)

RULE NUMBER: 55

IF: range to the threat is unknown

THEN: you are outside the range of enemy's weapon(s)
and enemy is outside the range of your weapon(s)

NOTE: 1. You may know a threat exists because of intelligence information or an ESM contact but you have no other contacts on any of your other sensors.

RULE NUMBER: 56

IF: you hold surface contact or air contact on 2D radar
and you have visual ID

THEN: range to the threat is close

RULE NUMBER: 57

IF: you hold surface contact or air contact on 2D radar
and you have no visual ID
and visibility is good

THEN: range to the threat is medium

RULE NUMBER: 58

IF: you hold air contact on 3D radar

THEN: range to the threat is far

RULE NUMBER: 59

IF: you hold air contact on 2D radar
and type of contact is ESM contact

THEN: range to the threat is very far

RULE NUMBER: 60

IF: type of contact is ESM contact
and you hold no surface contact
and you hold no air contact
and you detect MISSILESHIP ESM

THEN: range to the threat is very far

RULE NUMBER: 61

IF:	you have	visual ID
	and threat is	a MISSILE or an A/C with missiles
	and threat is	a reconn A/C or a MISSILE SHIP
	and threat is	a GUN SHIP or an AGI
	and it is	an enemy
	and enemy is	inside the range of your weapon(s)

THEN: take under fire -probability= 10/10

RULE NUMBER: 62

IF: you detect enemy ESM

THEN: determine type of threat -probability= 9/10

RULE NUMBER: 63

IF: threat is unknown

THEN: maintain increased state of alert until situation calls for more definitive action -probability= 9/10

NOTE: 1. You are not sure of the type and the degree of threat you may be facing.

APPENDIX C

QUALIFIERS AND CONDITIONS

QUALIFIERS:

1 threat is
- a missile
- an A/C with missiles
- a reconn A/C
- a missile ship
- a gun ship
- an AGI
- unknown

2 type of contact is
- air contact
- surface contact
- ESM contact

3 air contact speed is
- very fast
- fast
- slow
- unknown

4 contact movement is
- inbound
- holding station
- outbound
- closing
- orbiting
- opening
- unknown

5 5 consecutive bearings are
- the same
- not the same

6 each consecutive range is
- smaller
- same
- larger
- unknown

7 you have
- no visual ID
- visual ID

8 you detect

MISSILEHOMING ESM
TARGETING A/C ESM
MISSILE A/C ESM
GUNSHIP ESM
MISSILESHIP ESM
no ESM
enemy ESM

9 you are

inside the range of enemy's weapon(s)
outside the range of enemy's weapon(s)

10 it is

an enemy
a friendly
an unknown

11 enemy is

inside the range of your weapon(s)
outside the range of your weapon(s)

12 you hold

no surface contact
no air contact
surface contact
air contact on 2D radar
air contact on 3D radar

13 range to the threat is

close
medium
far
very far
unknown

14 visibility is

good
not good

CHOICES:

1 engage with HARPOON

2 engage with PHALANX

3 engage with 5/54

4 engage with TERRIER

5 fire CHAFF

6 alert EW's of the bearing

7 alert lookouts

8 determine its closest point of approach (CPA) to you

9 determine its speed

10 continue to monitor its position and/or ESM

11 be on alert for "splits" from the contact if it is within range of its missiles

12 do nothing - missile is outbound

13 do nothing - contact is outbound

14 stand by - contact is out of range

15 alter your course and speed to bring the enemy inside the range of your weapon(s)

16 alter your course and speed to move out of the range of enemy's weapon(s)

17 determine type of threat

18 take under fire

19 maintain increased state of alert until situation calls for more definitive action

APPENDIX D

A SAMPLE RUN OF THE TAO EXPERT SYSTEM PROTOTYPE

Note 1: This menu is displayed at the bottom of the screen each time the system asks user for any inputs.

"Enter number(s) of appropriate value(s), WHY for information on the rule being applied, QUIT to store data and exit or <H> for help"

RUN #1 (working an air and an ESM contact)

screen 1 looks like this:

```
type of contact is
    1    air contact
    2    surface contact
    3    ESM contact
```

you type: 1,3 <enter>

screen 2 looks like this:

```
you hold
    1    no surface contact
    2    no air contact
    3    surface contact
    4    air contact on 2D radar
    5    air contact on 3D radar
```

you type: 4 <enter>

screen 3 looks like this:

```
you have
    1    no visual ID
    2    visual ID
```

you type: 1 <enter>

screen 4 looks like this:

```
visibility is
    1    good
    2    not good
```

```
     you type: 1 <enter>

screen 5 looks like this:

     air contact speed is
          1     very fast
          2     fast
          3     slow
          4     unknown

     you type: 2 <enter>

screen 6 looks like this:

     you detect
          1     MISSILEHOMING ESM
          2     TARGETING A/C ESM
          3     MISSILE A/C ESM
          4     GUNSHIP ESM
          5     MISSILESHIP ESM
          6     no ESM
          7     enemy ESM

     you type: 3 <enter>

screen 7 looks like this:

     5 consecutive bearings are
          1     the same
          2     not the same

     you type: 1 <enter>

screen 8 looks like this:

     each consecutive range is
          1     smaller
          2     same
          3     larger
          4     unknown

     you type: 1 <enter>

screen 9 looks like this:

     These are recommendations only.    TAO is still required
     to make the final decision.

          "Press any key to display results"
```

screen 10 looks like this:

```
1     engage with TERRIER     :10/10
2     continue to monitor its position and/or ESM       :10/10
3     engage with 5/54     :5/10
4     alter your course and speed to bring the enemy inside
      the range of your weapon(s)     :5/10
5     alter your course and speed to move out of the range of
      enemy's weapon(s)     :5/10
```

The bottom of the screen displays this menu:
"All choices <A>, value>0 <G>, Print <P>, Change and rerun <C>, Quit/store <Q>, rules used <line number>, Help <H>, Done <D>:

RUN #2   (working a surface contact)

screen 1 looks like this:

```
     type of contact is
          1     air contact
          2     surface contact
          3     ESM contact

     you type: 2 <enter>
```

screen 2 looks like this:

```
     you have
          1     no visual ID
          2     visual ID

     you type: 1 <enter>
```

screen 3 looks like this:

```
     visibility is
          1     good
          2     not good

     you type: 1 <enter>
```

screen 4 looks like this:

```
     you detect
          1     MISSILEHOMING ESM
          2     TARGETING A/C ESM
```

3 MISSILE A/C ESM
4 GUNSHIP ESM
5 MISSILESHIP ESM
6 no ESM
7 enemy ESM

you type: 5 <enter>

screen 5 looks like this:

5 consecutive bearings are
1 the same
2 not the same

you type: 2 <enter>

screen 6 looks like this:

each consecutive range is
1 smaller
2 same
3 larger
4 unknown

you type: 1 <enter>

screen 7 looks like this:

These are recommendations only. TAO is still required
to make the final decision.

"Press any key to display results"

screen 8 looks like this:

1 determine its CPA to you :10/10
2 continue to monitor its position and/or ESM :10/10
3 be on alert for "splits" from the contact if it is
within the range of its missiles :10/10
4 engage with HARPOON :9/10
5 alert EW's of the bearing :9/10
6 engage with 5/54 :8/10
7 alert lookouts :8/10

The bottom of the screen displays this menu:
"All choices <A>, value>0 <G>, Print <P>, Change and rerun
<C>, Quit/store <Q>, rules used <line number>, Help <H>, Done
<D>:

LIST OF REFERENCES

1. OPNAVINST 3120.32 and NWIP 50 series publications.

2. Feigenbaum, E. A., and Feldman, J., Computers and Thought, Robert E. Krieger Publishing Company, Inc., 1981.

3. Feigenbaum, E. A., "Knowledge Engineering for the 1980's," Computer Science Dept., Stanford University, 1982.

4. Hayes-Roth, F., "Knowledge Based Expert Systems," Computer, October 1984.

5. Hayes-Roth, F. Waterman, D. A. and Lenat, D. B., Building Expert Systems, Adison-Wesley Publishing Co., 1983.

6. Exsys Manual, Exsys, Inc. P.O.Box 75158, Albuquerque, New Mexico, 87194, 1984.

BIBLIOGRAPHY

Allen, H. E. and Rannels, D. A., Examination of Battle-Group Commander Decision Processes and Support Information, Master Thesis, Naval Postgraduate School, Monterey, California, June 1982.

Booth, J. E., Debien, P. T., and Bensten, C. E., Analysis of Naval Tactical Decision Making: The Vagabond Approach, Master Thesis, Naval Postgraduate School, Monterey, California, December 1982.

Bowyer, B. J., Toward a Theory of Military Decisionmaking, Master Thesis, Naval Postgraduate School, Monterey, California, June 1983.

Davis, R. and Lenat, D., Knowledge-Based Systems in Artificial Intelligence, New York, NY, McGraw-Hill, 1980.

Duda, R. O. and Gaschnig, J. G., "Knowledge-Based Expert Systems Coming of Age," Byte 6, No. 9., 1981.

Edelson, E., "Expert Systems - Computers That Think Like People," Popular Science, September 1982.

Gesche, M. J. Bullock, R. A. and Widmaier, L. E., Tac*II An Expert Knowledge Based System for Tactical Decision Making, Master Thesis, Naval Postgraduate School, Monterey, California, June 1983.

Haas, N. and Hendrix, G. "An Aproach to Acquiring and Applying Knowledge," AAA 1, 1980.

Hassler, C. C., A Simulation of Information Load and its Affect on Tactical Decision Making, Master Thesis, Naval Postgraduate School, Monterey, California, June 1983.

Hayes-Roth, F., "The Knowledge Based Expert System: A Tutorial," Computer, September 1984.

Loumakis, P., A Decision-Making System for The Officer in Tactical Command (OTC) Using Artificial Intelligence Techniques, Master Thesis, Naval Postgraduate School, Monterey, California, October 1982.

Michaelson, R. and Michie, D., "Expert Systems in Business," Datamation, November 1983.

Nau, Dana S., "Expert Computer Systems." Computer, February 1983.

Nielson, N. J., Problem-Solving Methodsin Artificial Intelligence, McGraw-Hill Book Co., 1971.

Stefik, M., and others, "The Organization of Expert Systems, A Tutorial," Artificial Intelligence 1982.

Tversky, A. and Kahneman, D., "Judgement Under Uncertainty: Heuristics and Biases," Science, 1974.

Winston, P. H., Artificial Intelligence, Addison-Wesley Publishing Co., 1977.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22304-6145	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, California 93943-5002	2
3.	Professor Tung Bui Code 54Bd Department of Administrative Sciences Naval Postgraduate School Monterey, California 93943-5000	2
4.	Professor Tacarad Sivasankaran Code 54Sj Department of Administrative Sciences Naval Postgraduate School Monterey, California 93943-5000	5
5.	LCDR Sreten Zivovic, USNR Naval Military Personnel Command NMPC-9 Washington D.C. 20370-5000	2
6.	LCDR Ted Kral Code 44 Naval Ocean Systems Center San Diago, California 92152-5000	1
7.	Computer Technology Programs Code 37 Naval Postgraduate School Monterey, California 93943-5000	1

END

DTIC

7-86